NQSTI National Quantum Science and Technology Institute

Deterministic and enhanced single-photon emission in an integrated ring resonator

Vincenzo Macrì[1], **Marco Liscidini**[1]

1. University of Pavia, Department of Physics, via Bassi 6, 27100 Pavia, Italy

Abstract: We present a single-photon source utilizing spontaneous emission in a ring resonator, offering precise control of emission rate and mode. This scalable method employs asymptotic fields for advanced quantum photonic applications with high performance.

Single-photon sources are indispensable for quantum technologies, enabling non-Gaussian light states essential in quantum communication, computing, and metrology. Despite advancements in integrating quantum dots into micropillars [1] or using defect-based emitters in photonic crystals [2], achieving practical, high-quality single-photon sources remains a formidable challenge. Among the promising platforms are ring resonators which can exhibit a finesse of several thousand, enabling enhanced light-matter interaction. Among the promising platforms are ring resonators which can exhibit a finesse of several thousand, enabling enhanced light-matter interaction. Some proposals employ such structures combined with nanoscale emitters to create single-photon source [3,4].

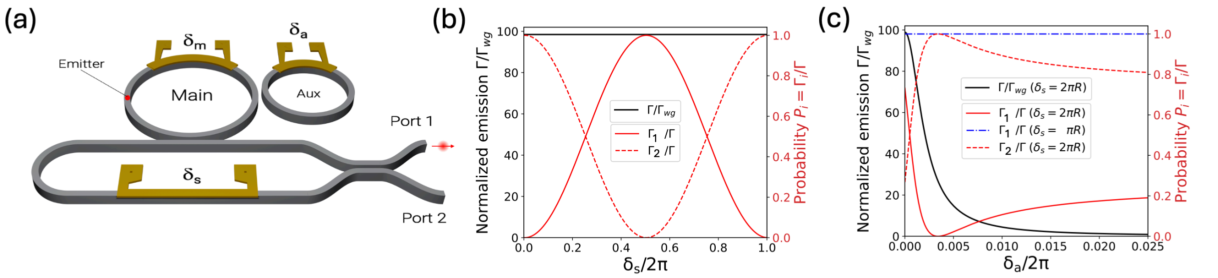

Fig. 1 (a) Device sketch. (b) Emission rate and output probability for each port Γ_i vs. Sagnac interferometer phase δs. (c) Emission rate and output probability for each port Γ_i vs. auxiliary ring phase δa normalized to the waveguide emission rate.

Our work introduces a single-photon source design based on a ring resonator coupled with a Sagnac interferometer and an auxiliary ring. This architecture provides deterministic control over the emission rate and output mode, with tunable parameters enabling compensation for fabrication imperfections. The quantization of electromagnetic fields in terms of asymptotic modes simplifies emission rate calculations and mode-specific probabilities [5]. Key results are illustrated in Fig. 1. By tuning the Sagnac interferometer phase δs, interference between clockwise and counterclockwise modes enables deterministic selection of output ports, with emission rates normalized to waveguide benchmarks. Emission probabilities for each port Γ_i can be precisely controlled, as shown in Fig. 1(b). Additionally, the auxiliary ring enables selective enhancement or suppression of emission rates by fine-tuning the phase δa, as showed in Fig. 1(c). These features ensure significant extraction efficiencies and robust control over single-photon properties.

This approach offers a scalable, high-performance platform for deterministic single-photon emission, tailored to integrated quantum photonic systems. It paves the way for advanced quantum technologies, enabling practical and versatile applications in quantum communication, metrology, and computing.

Example References

[1] P. Senellart, et al., "High-performance semiconductor quantum-dot single-photon sources," *Nat. Nanotechnol.* 12, 1026 (2017).
[2] B. Ruf, et al., "Optically Coherent Nitrogen-Vacancy Centers in 4H-Silicon Carbide for Quantum Communication," Phys. Rev. X 9, 031021 (2019).
[3] Ł. Dusanowski, et al., "Purcell-Enhanced and Indistinguishable Single-Photon Generation from Quantum Dots Coupled to On-Chip Integrated Ring Resonators," Nano Lett. 20, 5627 (2020).
[4] D. Martin-Cano, et al., "Chiral emission into nanophotonic resonators," ACS Photonics 6, 961 (2019).
[5] M. Liscidini, et al., "Asymptotic fields for a Hamiltonian treatment of nonlinear electromagnetic phenomena," *Phys. Rev. A* 85, 013833 (2012).